INSTALLATION OF A GROUND WATER HEAT PUMP FOR THE AVERAGE HOUSEHOLD

A Senior Thesis

by

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ABSTRACT

Ground water is an economic, efficient and unlimited source of energy. It is known that the high specific heat of water allows a high yield of heat energy.

Ground water is sent through various components that raise and lower water temperature to produce warm or cool air and hot water.

With storage management, as much as 85 percent of the United States has enough water for heat pump usage.

When a well is drilled for heat pump use, it should be designed to produce about 10,000 gallons per day. A non-heat pump household well yields about 400 gallons per day. A well pump should be able to supply 30 to 50 psi to household fixtures. The well screen should allow a water velocity of 0.1 feet per second. The well pump should be tested in situ by the following methods: the constant rate test; the recovery test; and the step test.

Used ground water can be disposed of by the single well system which needs 100 feet of vertical separation for every 12,000 BTUs of heat energy supplied. The alternating two well disposal system needs two pumps to operate. It has been found that both of these methods are expensive and impractical. The best system is the non-alternating two well disposal system which uses one pump and is the least expensive.

Stainless steel tubing and components should be used in a heat pump system to minimize chemical deterioration. Equipment should be rinsed with a 2:1 solution of water and bleach.

The higher the ground water temperature, the less work is put on a heat pump system to operate. In central Ohio, ground water temperature is about 53 degrees Fahrenheit. Ground water heat pumps can function efficiently at 39 degrees Fahrenheit. The average efficiency of a ground water heat pump is 330 percent.

Central Ohioans can expect to pay between $1250 and $3750 for a complete ground water heat pump system, with a payback period of about 10 years.

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INTRODUCTION

The concept of the heat pump was originally discovered in 1824 by Nicholas Carnot. Thirty years later, Lord Kelvin announced that heat could be obtained from refrigerating equipment. However, major advances in heat pump design and operation were slow until the 1950's. Since then, heat pump production has been continuously growing (Anon, 1983).

Few people realize the potentials of the ground water heat pump. The purpose of this paper is to present an understandable view of a heat pump system. This paper discusses operation techniques, components of a heat pump system, regional costs and efficiency. In addition, well drilling techniques are given.

Hopefully, the future consumer will be able to use the information compiled within this paper to his or her advantage.

GROUND WATER AS AN ENERGY SOURCE

Ground water as an energy source is sometimes a difficult concept. Unlike oil and gas, which can be burned, or fast-flowing water which can produce hydroelectric energy, ground water contains specific thermal properties which can be utilized through the process of heat exchange.

Water, while in the liquid state, has the ability to store heat energy. The amount of heat needed to raise the temperature of a unit weight of any substance one degree Fahrenheit is that substance's specific heat. The specific heat of water is one of the highest of all substances. Because of water's high specific heat, more energy is needed to raise its temperature than is needed for other substances. However, the important fact is that when the temperature of water is lowered b one degree, more energy per unit weight can be extracted than most substances are capable of yielding. In other words, if the same amount of heat is put into a pound of water and a pound of another substance, the water will be able to absorb and store much more heat than the other substance. Further, when the temperature of the water is lowered by one degree, that amount of stored heat can be obtained and utilized. Therefore, by this method, water becomes a source of geothermal energy. Stored geothermal energy can be tapped by a ground water heat pump and used to heat and cool a building and in many cases, supply hot water for the building.

HEAT PUMP DESIGN

A heat pump is designed to transfer heat from a cool region to a warmer region. An example of a heat pump is the common refrigerator found in virtually every household.

A ground water heat pump, sometimes referred to as a water-to-air heat pump, transfers thermal energy from the ground water to a building in the winter months, and from the building back into the ground water during the summer months. More simply, a ground water heat pump can act as an air conditioner in the summer and a heating mechanism in the winter.

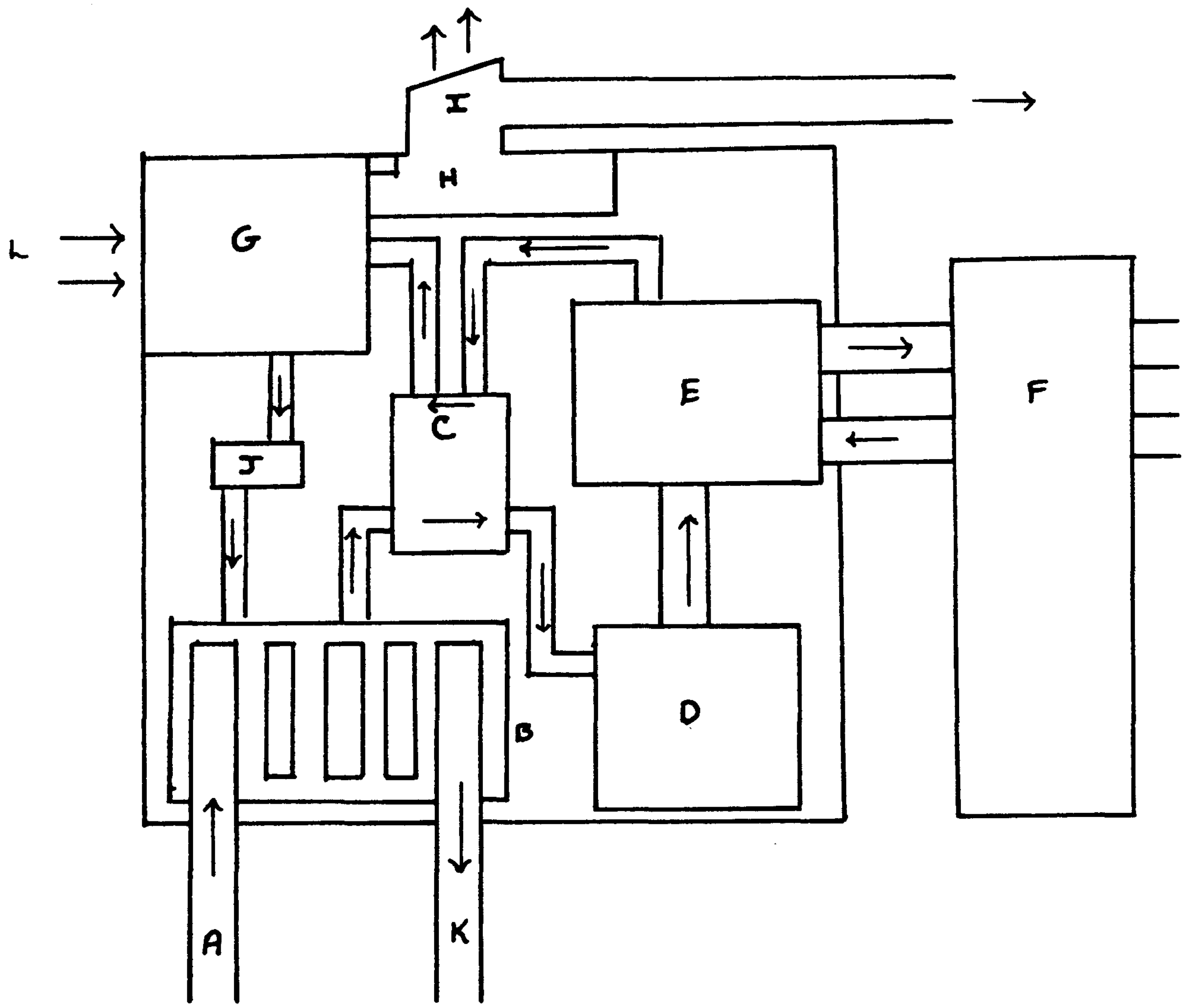
Whether in the heating mode or cooling mode a transfer medium, a liquid refrigerant, is necessary. The most commonly used refrigerant is Freon, a trade name of the E.I. Dupont De Nemours Company. Freon has the ability to absorb or reject heat from the ground water, depending on exerted temperatures and pressures (Anon, 1983).

Let us first consider the heating mode (Figure 1). Ground water is injected through a coil to the water/refrigerant heat exchanger, otherwise called an evaporator. Simultaneously, liquid Freon is sent through an adjacent tube and absorbs heat from the ground water. Through heat absorption, liquid Freon becomes a gas approximately 10 to 30 degrees cooler than the ground water. The gas is then passed to a hermetic compressor which compresses it to a higher temperature and pressure. The heated Freon gas is then passed to an air/refrigerant heat exchanger where air is heated and then released into the home via ductwork, at approximately 105 degrees Fahrenheit. Because heat is now being given off, the Freon

FIGURE 1

THE HEATING MODE

source



A. Supply Well

B. Water/Refrigerant Heat Exchanger

C. Reversing Valve

D. Compressor

E. Domestic Hot Water Heat Exchanger

F. Hot water tank

G. Air/Refrigerant Heat Exchanger

H. Air Handler

I. Supply Air

J. Expansion Device

K. Discharge Well

L. Return Air

condenses into a liquid again and is sent through an expansion device which lowers the pressure and thereby lowers the temperature. The cooled liquid Freon is sent back into the initial heat exchanger and the process is repeated (Hughes, 1980).

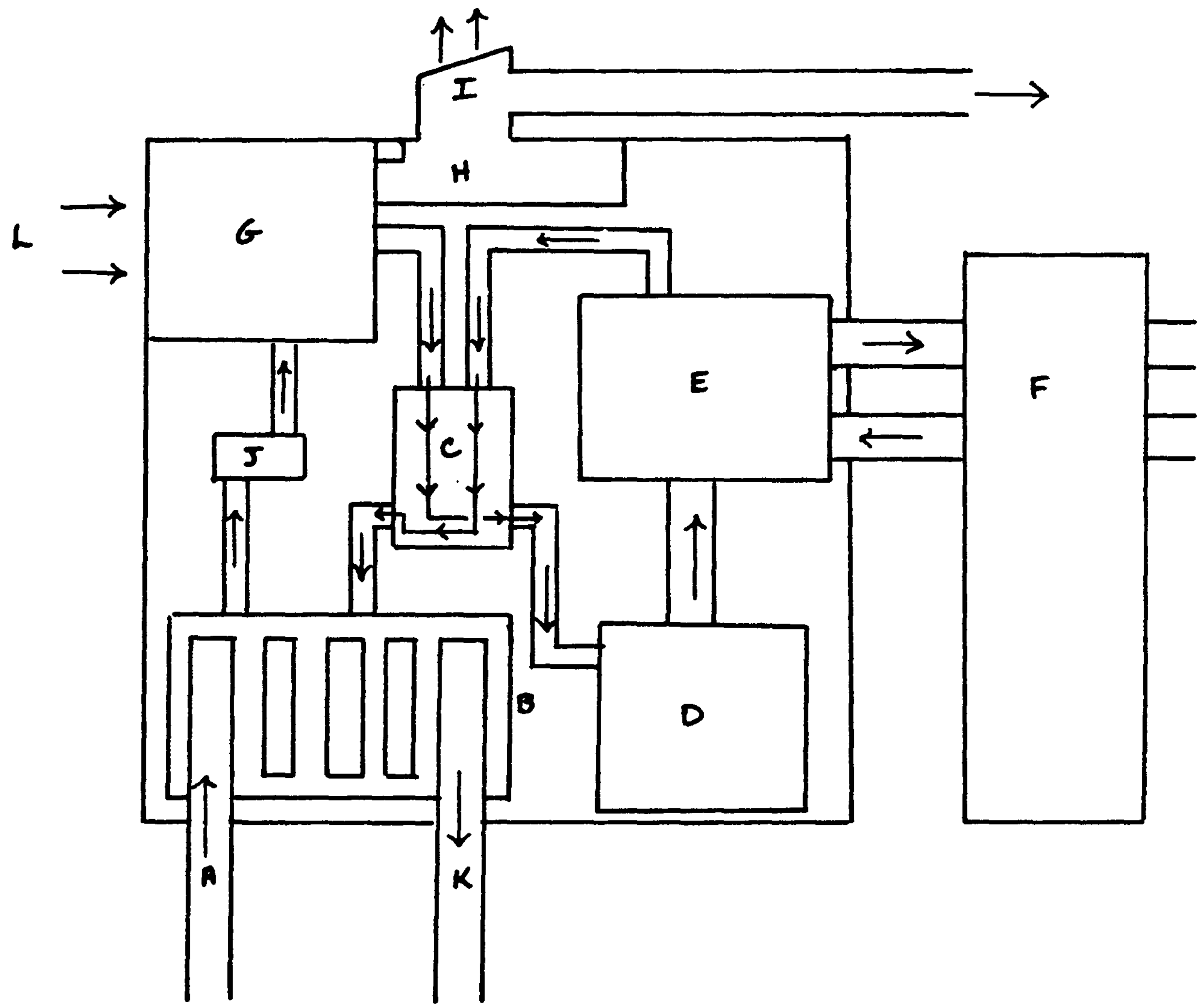
Let us now consider the cooling mode (Figure 2), which is actually the heating cycle in reverse. The liquid Freon, while in the air/refrigerant heat exchanger, absorbs heat from the air within the house. The gaseous Freon is then passed to the compressor where the temperature and pressure is increased. The gas comes into contact with the ground water by the water/refrigerant heat exchanger and is cooled. The expansion device further lowers the temperature and pressure of the liquid Freon. The cooled Freon is sent back to the air/refrigerant heat exchanger and cool air is circulated through the house. As with the heating mode, the cooling cycle is a continuous process (Hughes, 1980).

In order for a heat pump to operate as both a heating and cooling mechanism, it must contain a refrigerant reversing valve. This valve allows the flow of Freon to be reversed through the heat exchangers.

Hot water for domestic use can also be obtained from ground water heat pumps. During both the heating and cooling modes, hot, gaseous Freon can be used to supply hot water. Units must be specially equipped for this pro-cess by installing a heat exchanger situated between the compressor and the reversing valve.

FIGURE 2

THE COOLING MODE



A. SUPPLY WELL
B. WATER/REFRIGERANT HEAT EXCHANGER
C. REVERSING VALVE
D. COMPRESSOR
E. DOMESTIC HOT WATER HEAT EXCHANGER
F. HOT WATER TANK
G. AIR/REFRIGERANT HEAT EXCHANGER
H. AIR HANDLER
I. SUPPLY AIR
J. EXPANSION DEVICE
K. DISCHARGE WELL
L. RETURN AIR

GROUND WATER AND WELL DEVELOPMENT

Ground water, by definition, is the water which flows through rock and soil, and which fills the cracks and pores. It eventually surfaces in the form of a spring, stream, lake or ocean (Fetter, 1980). It has been determined that over 93 percent of the United State's water supply is underground, but that most of the water used comes from lakes, streams and rivers. According to a 1976 study done by the National Water Well Association (NWWA), 75 percent of the United States has enough water to supply heat pumps. With storage management, 85 percent of the United States has adequate water supplies for heat pump usage (Anon, 1982). The fact that ground water is replenished through the unending hydrologic cycle gives ground water great economic potential, if properly utilized.

Ground water has definite advantages over surface water. These include a fairly constant supply due to the hydrologic cycle, constant temperature, generally pollutant free, little loss through evaporation and small developmental space requirements. These advantages are often preferred by industry and communities alike.

Ground water is obtained when a well is drilled in the proper location. There are also different methods for well drilling. An experienced contractor will easily be able to determine the necessary drilling method for the particular situation.

Wells should be situated on the highest ground possible, and should be higher than any nearby pollution source. A well should be surrounded by a well casing that extends above ground to minimize possible pollutant infiltration.

The design of a well should be compatable with the local geology and ground water supply. A well should have a proper diameter and depth according to the formation by which it is drawing. Information on water availability, abundance and depth, along with local strata descriptions and other pertinent data can be obtained from a well log data sheet supplied by the contractor.

Every household is different in its use of water. When drilling a well for the use of a ground water heat pump, well sizing is an important factor. One aspect to consider is the average daily consumption of water in the household. The average water consumption in a home is approximately 70 gallons per day. However, a home that utilizes many water appliances such as a dishwasher and a clotheswasher may use up to as many as 100 gallons per day. Keeping this in mind, most wells are designed to produce between 300 and 400 gallons per day. Once a ground water heat pump is installed, a well may be required to produce 10,000 gallons per day (Gass, 1980). For some, this large quantity of water needed to operate a ground water heat pump could prove to be a disadvantage.

The peak demand for water per household is another factor in well drilling. Many households require large quantities of water in the early morning, before meals and before bedtime. When a shower, dishwasher, clotheswasher or heat pump is used qualifies as a peak demand period (Figure 3).

FIGURE 3

PEAK DEMANDS AND FLOW RATES

OF WATER APPLIANCES

Table

Water Uses	Peak Demand Allowance for Pump	Individual Fixture Flow Rate
	gpm Column 1	gpm Column 2
Household Uses		
Bathtub or tub-and-shower combination	2.00	8.0
Shower only	1.00	4.0
Lavatory	.50	2.0
Toilet—flush tank	.75	3.0
Sink, kitchen—including garbage disposal	1.00	4.0
Dishwasher	.50	2.0
Laundry sink	1.50	6.0
Clothes washer	2.00	8.0
Irrigation, Cleaning and Miscellaneous		
Lawn irrigation (per sprinkler)	2.50	5.0
Garden irrigation (per sprinkler)	2.50	5.0
Automobile washing	2.50	5.0
Tractor and equipment washing	2.50	5.0
Flushing driveways and walkways	5.00	10.0
Cleaning milking equipment and milk storage tank	4.00	8.0
Hose-cleaning barn floors, ramps, etc.	5.00	10.0
Swimming pool (initial filling)	2.50	5.0

Source: Understanding Heat Pumps, Ground Water and Wells - Anon, 1983.

Yet another factor to be resolved is the potential of the aquifer to yield water. An aquifer is rock or sediment that is saturated and capable of transporting economic amounts of water (Fetter, 1980). If a well is overdeveloped or overpumped, aquifer drawdown may develope. That is, more water is being taken from the aquifer than is being replaced. The result of drawdown is a smaller than normal yield. Another problem associated with an inadequate well is well interference. This occurs when a well is overpumped and begins to draw on a neighboring well. In this case, both wells experience a smaller yield. The problem of aquifer yield can be resolved through the examination of regional well logs by a contractor. Proper spacing of wells and water re-injection will reduce the affects of well interference.

When designing a well, the pump capacity must first be determined. If the pumping ability exceeds the well capacity, the water level in the well will fall, perhaps to the point of damaging the pump.

The pumping head (the pump's ability to lift) should be enough to supply water to household fixtures at a reasonable pressure. For most households, the average pressure range is 30 to 50 psi. To determine the pumping head, add the amount of vertical lift at the point of the pumping level within the well to the point at which water is delivered, plus the total friction losses (Gass, 1980). Tables for friction loss are available.

The next step is to establish the size of the well casing, which contains the pump. The diameter is usually one to four inches larger than the pump diameter.

Now the well can be drilled. When the drill bit comes into contact with an aquifer, yield tests should be made. The yield can be determined from the known pump diameter and the permia-bility and the thickness of the water-bearing strata. Often, drilling deeper increases the aquifer yield.

To construct the well, a screening device is usually installed. A screen is designed to allow the free flow of water into the well while blocking materials such as sand or gravel from the well. Screen size is a function of aquifer permiability and water flow rate. In order to maintain a consistant flow of water, the screen should allow a water speed of 0.1 feet per second (Gass, 1980). The driller should then clean the well of any debris that has collected in order to promote maximum well efficiency.

The final and most important step in well design is testing the pump in situ. According to Jim Poehlman, director of technical services for the National Water Well Association, three tests should be performed. Before these tests are run, the well should remain unpumped for 24 hours. This determines the static water level, which is the constant amount of water available in an unused well (Poehlman, 1981).

Not Testing Pump -But Well

To begin, a constant rate test is run. Water level measurements are taken while the pump runs at 1.5 times the required rate of flow. The measurement intervals are as follows: every 60 seconds for the first 10 minutes; every 5 minutes for the next 50 minutes; every 10 minutes for the next 1½ hours; and then every 60 minutes for the next 4½ hours, continuing until the level of the water stabilizes (Poehlman, 1981).

The results of the constant rate test determine the amount of drawdown, which is the difference between the static water level and the pumping level (the distance to the water in the well while pumping). This test also establishes the spacing distances between adjacent wells and the depth to which the pump can be placed.

The next step is the recovery test. Immediately after the constant rate test, the pump is turned off and the water level is recorded every 60 seconds for the first 15 minutes. Continuing, the levels are recorded every 10 minutes for the next 45 minutes. The water levels should be recorded every hour until the water has returned to its initial level. The recovery test is a verification of the constant rate test (Figure 4), (Poehlman, 1981).

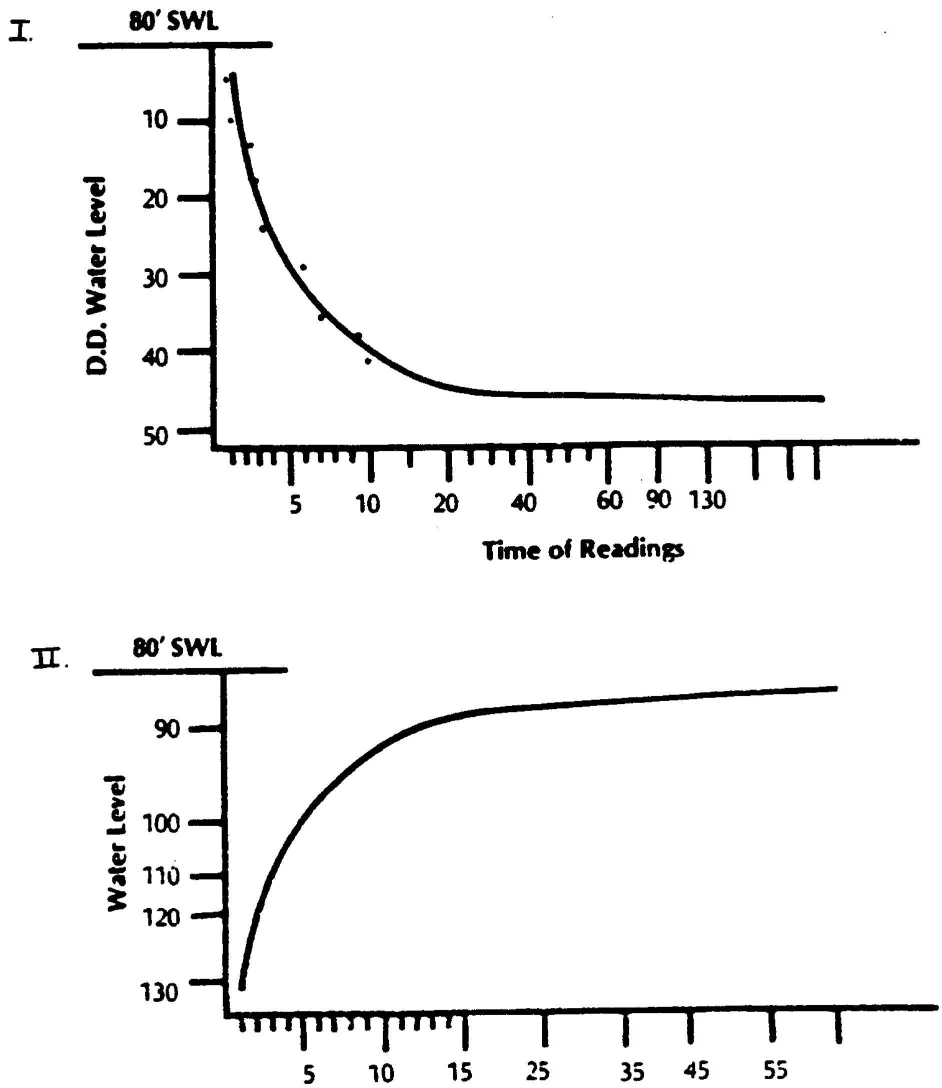
The final part is the step test. The pump is turned on again at about 25 percent of the required rate of flow until the level of the water in the well has stabilized. The rate of pumping is then stepped up by 25 percent. This test is performed until the well is supplying about 1.5 times the appropriate amount of flow (Poehlman, 1981). This test determines the specific capacity of the well. Specific capacity is an expression of the well's productivity. It is expressed in gallons per minute (gpm) of flow for each foot of difference (Figure 5), (Fetter, 1980).

Performed correctly, these tests should indicate a well built system.

FIGURE 4

VERIFICATION GRAPHS OF CONSTANT

RATE TEST (I) AND RECOVERY TEST (II)

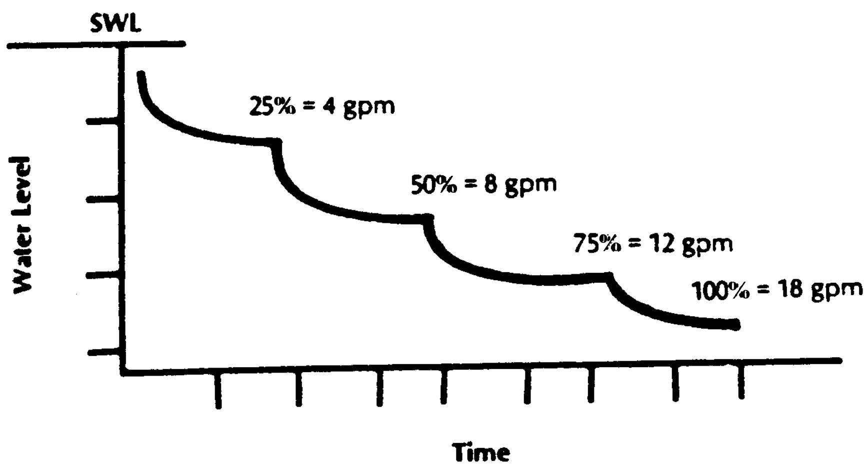


source: Testing Wells for Ground Water Heat Pump Use - J. Poehlman, 1981

FIGURE 5

GRAPH OF STEP TEST ILLUSTRATING

WELL'S PRODUCTIVITY



Source: Testing Wells for Ground Water Heat Pump Use - J. Poehlman, 1981

DISPOSAL METHODS

Since ground water heat pumps give back the same amount of water that they use, a disposal area must be designed for the discharge of water.

There are many different methods available for discharging water. The water can be returned to the aquifer; secondary uses such as garden and lawn watering; agricultural or industrial uses; discharge to surface features such as ponds and lakes, rivers and streams, or sewer systems.

The NWWA recommends restoring the water to the aquifer or disposal by means of secondary uses (Anon, 1983).

A closed system is necessary when restoring the water to the aquifer. There are several disposal systems that can be utilized, such as the single well system, the alternating two well system and the non-alternating two well system.

The single well system is an impractical method of water disposal. For every 12,000 BTUs of heating/cooling supplied per home, 100 feet of vertical separation from the supply point to the disposal point is required. For example, a 70,000 BTU heat pump system would need 583 feet of vertical separation.

The alternating two well system is rarely used due to the expense of installing two pumps. This system has a return well and a supply well that alternate with the winter and summer seasons. During the winter, the return well sends cool water back to the aquifer. During the summer, the return well becomes the supply well and takes cool water from the aquifer.

The non-alternating two well system incorporates a supply well and a return well that utilizes one pump and does not operate seasonally. The return well should be drilled an adequate distance from the supply well in order that no thermal effects occur between the two. One problem that occurs with the use of this method is the screens on the wells often become encrusted with chemical sediments, slowing the flow of water. When the alternating system is practiced, incrustation is minimal.

Discharge water should be returned to the original aquifer from which it was drawn. Otherwise, the chemical inequivalency could cause precipitation of hydroxides or salts from solution (Anon, 1983). Such precipitation may cause clogging of the aquifer.

CHEMICAL PROBLEMS

Various parts of the well and pumping components are susceptable to chemical incrustation and corrosion. High concentrations of calcium, magnesium, iron and salts often cause incrustation and scaling of the water-side heat exchanger coils. Hydrogen sulfide corrodes metal vigorously (Persons and Hart, 1980). The best prevention is to install a stainless steel heat exchanger.

All well and pump equipment needs to be disinfected with a chlorine solution before installation. The solution can be made by mixing two parts water to one part bleach. For each 100 gallons of water, two quarts of the chlorine solution should be added (Anon, 1983). The use of this disinfectant prevents biological incrustation of the system.

Water that is highly acidic tends to corrode copper tubing. Therefore, a cupro-nickle tubing is more practical since scale flakes off its surface. However, hydrogen sulfide, even in small quantities easily corrodes either metals. If necessary, stainless steel may be used.

POLLUTION FROM FREON

Tests run by the Freon Products Laboratory of E.I. Dupont De Nemours Company indicate that Freon leakage into water offers no human or environmental threat. Dupont produces two brands of Freon refrigerant: Freon 12 and Freon 114. The solubility of Freon 12 and Freon 114 is very low in water and continues to decrease as temperature increases (Anon, 1983).

The probability of Freon leaking into the water system is low since at no point in the system do the two come into contact.

TEMPERATURE VARIATIONS

Ground temperatures remain fairly constant year-round, regardless of surface temperature variations. In other words, during the winter season, the ground temperature is warmer than the air above, and in the summer, the ground temperature is cooler than above. Water can hold five times more heat than its equivalent weight of air, therefore, water will yield more heat at lower surface temperatures than air will. Air-to-air conditioning or heating is highly dependent on the seasonal outside temperature.

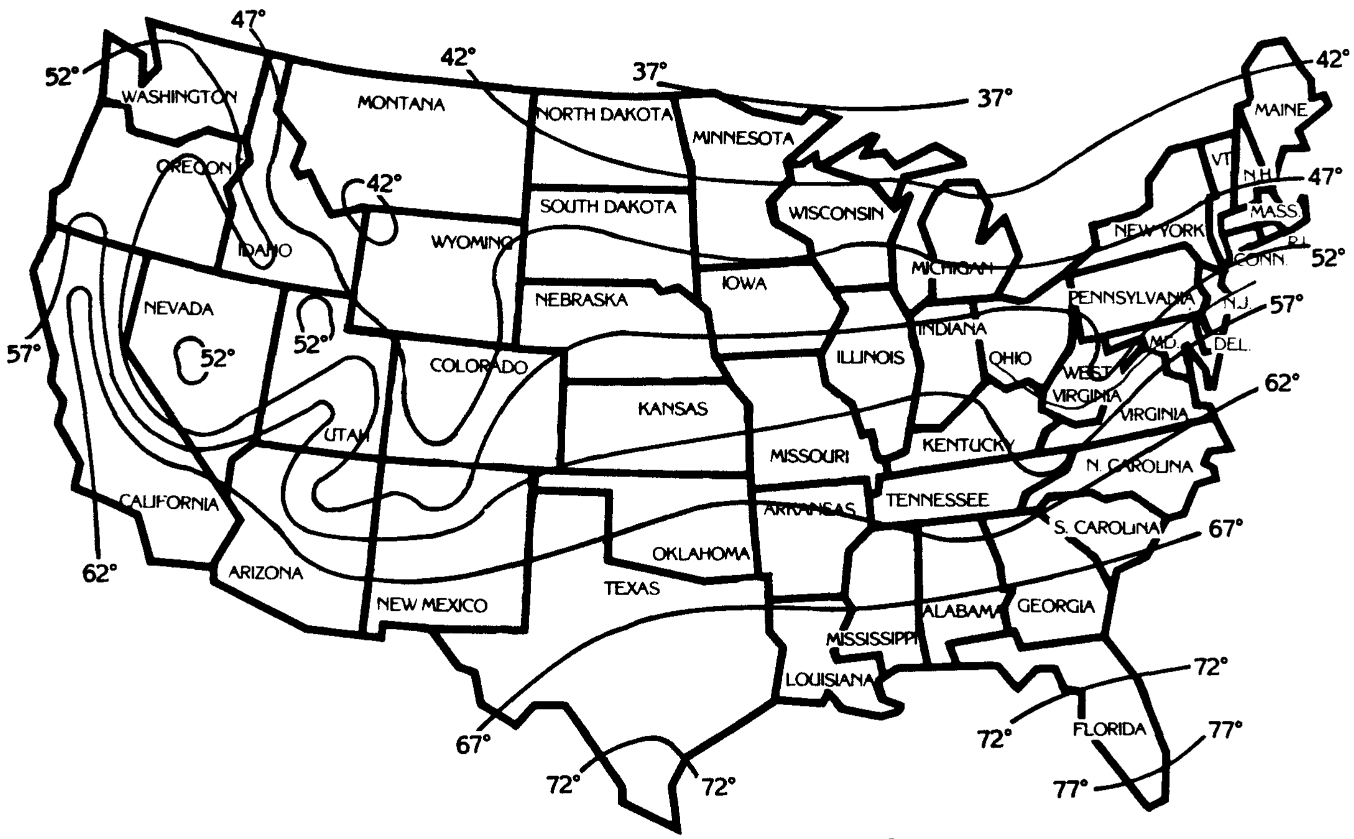
Ground water temperatures vary throughout the United States (Figure 6). In central Ohio, the average ground water temperature is approximately 53 degrees Fahrenheit. Since ground water heat pumps maintain efficient operation as low as 39 degrees Fahrenheit (Anon, 1983), central Ohioans have the opportunity to utilize heat pumps. In fact, Canada is the only portion of land within the continental United States whose ground water temperature is below 39 degrees Fahrenheit. The higher the ground water temperature, the more efficient a heat pump becomes since less stress is put on the system. As seen by Figure 6, the south exhibits higher ground water temperatures than the north and will see the greatest heat pump efficiency.

Parts, not all

A small risk of changing the temperature of the aquifer when heated water is returned to the ground is possible. However, tests indicate the changes in temperature are very small and equilibrium is soon established and remains constant. A test conducted on a system in Columbus, Ohio, indicated that the aquifer temperature reached equilibrium within five years of use,

FIGURE 6

AVERAGE TEMPERATURES OF SHALLOW GROUND WATER IN THE UNITED STATES



Source: Understanding Heat Pumps, Ground Water and Wells - Anon, 1983.

and has been constant for the duration of a 20-year test (Anon, 1983).

EFFICIENCY

A subject of major concern is the potential efficiency of ground water heat pumps. The efficiency of ground water as compared to other means of heating and cooling is measured in terms of the Coefficient of Performance (COP). By definition, the COP is the cooling or heating output, divided by the energy input. For the heating mode the equation can be written: $COP = H_h/E$. As the COP increases, the efficiency of the system increases (Anon, 1983).

Another method of measuring heat pump cooling efficiency is by the Energy Efficiency Ratio (EER). It is the BTU per hour of cooling per watt of energy input. The EER is equivalent to the COP when multiplied by 3.412 (Anon, 1983).

As an example, a coal furnace has a COP of 0.60. That is, this system can produce 60 BTUs of heat for every 100 BTUs the system uses. Therefore, the coal furnace has an efficiency of 60 percent.

On the other hand, an air-to-air heat pump utilizes a "free" energy source, therefore its COP is usually greater than 1.0 or 100 percent. COPs often reach as high as 2.0 or 200 percent (Anon, 1983). This high percentage is possible due to the idea of "free" energy.

Likewise, a ground water heat pump transfers "free" energy from the ground water. The average COP for a ground water heat pump is about 3.3 (Anon, 1983). In comparing the COP of an air heat pump with that of a ground water heat pump, clearly the ground water heat pump is more efficient.

Measuring the EER of a ground water heat pump during the cooling mode indicates that efficiency can reach as high as 1300 percent, while efficiency for an air-to-air heat pump reaches only an average of 790 percent (Anon, 1983).

Figure 7 lists various heating and cooling methods, along with their coefficient of performances and energy inputs and outputs.

FIGURE 7

ENERGY INPUT AND OUTPUT AND COEFFICIENT

OF PERFORMANCE FOR VARIOUS HEATING/COOLING SYSTEMS

System	COP	Energy Input	Energy Output
Electrical resistance	1.0	100	100
Fuel oil	.70	100	70
Propane	.75	100	75
Natural gas	.80	100	80
Air-to-air heat pump	1.5	100	150
Ground water heat pump	2.8	100	280
Reversing ground water heat pump	3.2	100	320
Direct cooling	20.0	100	2,000

Source: Understanding Heat Pumps, Ground Water and Wells - Anon, 1983.

COSTS

The installation cost of a ground water heat pump is often higher than that of any other system. Although this is an initial disadvantage, the lower maintenance cost, higher efficiency and heating/cooling abilities make the ground water heat pump very attractive. Figure 8 lists the annual costs of five different heating/cooling devices for a typical home in Columbus, Ohio. The heating load of the house is 72,000 BTUs per hour at -5 degrees Fahrenheit (Anon, 1983).

The economic advantages are also dependent on the regional setting and climate. As previously discussed, warmer ground water temperatures increase heat pump efficiency because less work is placed on the system. Also, regions of high rainfall tend to have shallow aquifers, thereby decreasing well depth and subsequently lowering the costs. Figure 9 illustrates the variations in cost throughout the continental United States. According to a 1978 NWWA Water Survey, central Ohioans can expect to pay an average of $1250 to $3750 for a complete system (Anon, 1983). \well only/ check local contrator

Of course, the amount of money saved ultimately depends on the lifestyle of a particular household. The payback period is usually less than ten years.

FIGURE 8

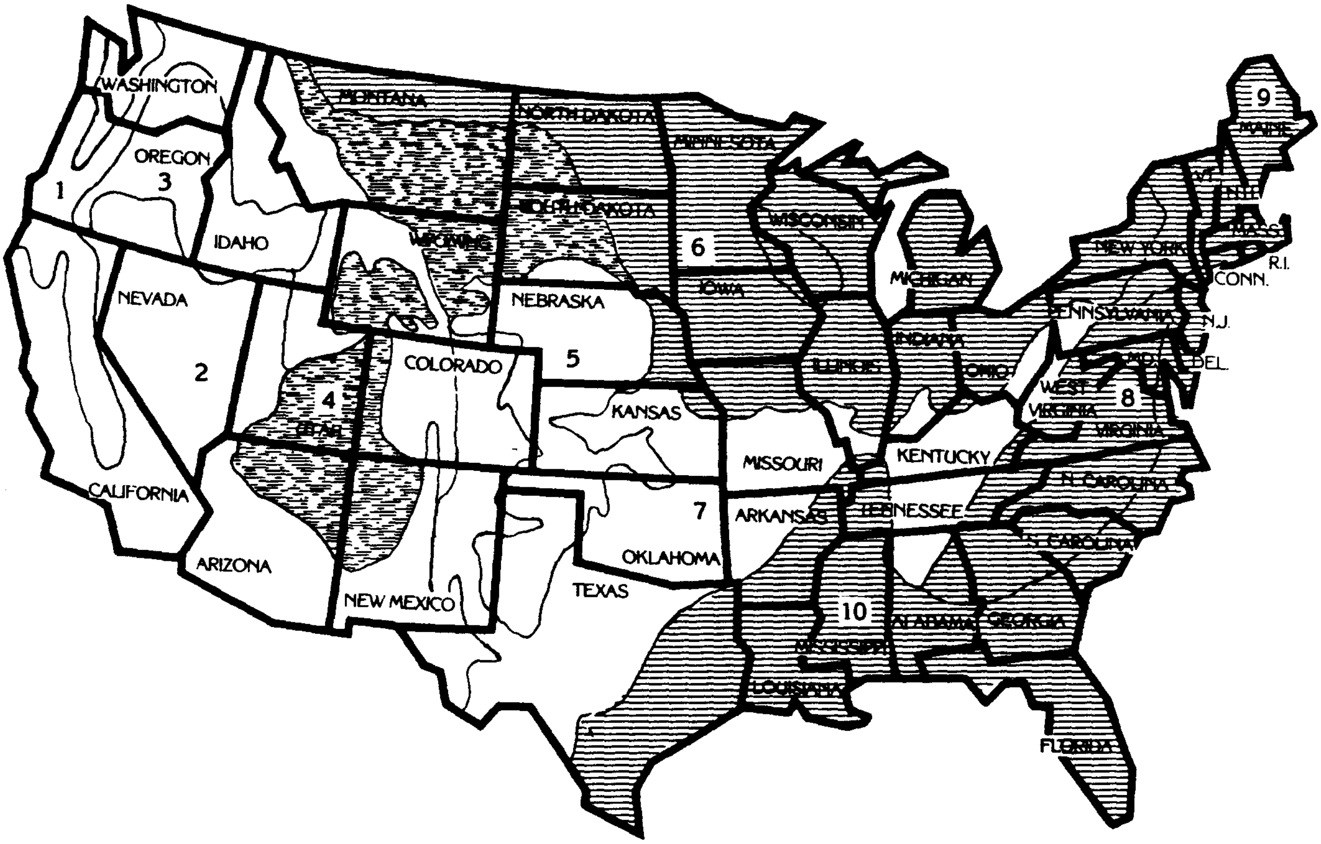
ANNUAL COST ESTIMATES FOR A COLUMBUS, OHIO, HOME WITH A HEATING LOAD OF 72,000 BTUs PER HOUR AT -5 DEGREES FAHRENHEIT

Propane gas	
1,720 gal. fuel @ $.94/gal.	$1,548.00
500 kwh electricity @ $.05/kwh (for operating blower)	25.00
Tank rental	150.00
	$1,723.00
Electric furnace	
24,238 kwh electricity @ $.05/kwh	$1,211.90
Oil furnace	
1,146 gal. fuel oil @ $.90/gal.	$1,031.40
753 kwh electricity @ $.05/kwh (for operating blower)	37.65
	$1,069.05
Natural gas	
152,128 cu. ft. natural gas @ $.30/100 cu. ft.	$ 456.30
550 kwh electricity @ $.05/kwh (for operating blower)	27.50
	$ 483.80
Ground water source heat pump	
7,788 kwh electricity @ $.05/kwh for operating pump compressor and blower	$ 389.40

Source: Ground Water Heat Pumps - Anon, 1982.

FIGURE 9

REGIONAL WELL DATA AND WATER SYSTEM COSTS



Ten Major Ground Water Regions	Average Well Depth	Cost to Drill Average Well	Range of Depths	Pump Cost At List 10 GPM	Drop Pipe Cost at List 160# Plastic	Total Well Cost Range 1978 NWWA Water Survey
#1 Western Mountain Ranges—6"	250	$3,770	100-500	$470	$140	$2,000-5,000
#2 Alluvial Basins—6"	400	$6,188	200-1,000	$610	$245	$2,600-7,000
#3 Columbia Lava Plateau—6"	200	$3,042	50-1,000	$470	$105	$1,550-6,000
#4 Colorado Plateau—6"	300	$4,029	110-500	$610	$175	$2,000-5,000
#5 High Plains (Ogallala Aquifer)—4"	300	$1,458	50-500	$610	$175	$1,250-5,000
#6 Glaciated Central Region—4"	150	$1,680	50-300	$386	$85	$1,250-3,750
#7 Unglaciated Central Region—4"	200	$2,058	100-400	$470	$105	$1,550-4,000
#8 Unglaciated Appalachians—6"	250	$2,600	200-500	$470	$140	$2,350-6,000
#9 Glaciated Appalachians—6"	100	$1,385	50-200	$360	$52	$1,150-3,750
#10 Coastal Plain—4"	75	$640	25-250	$360	$42	$1,250-3,250

Average Cost for Well and Pumping System for 10 GPM $2,400-$2,800
Average Cost for Cased Well Only $1,600-$2,000
Average Well Depth Is 200 Feet

Source: Understanding Heat Pumps, Ground Water and Wells - Anon, 1983.

CONCLUSION

This paper has made an attempt to explain the concept of the ground water heat pump to the layman. For the consumer seriously considering the installation of a ground water heat pump, there is a vast amount of information that lists specifics of particular interest.

Consumers should keep in mind that when installing a ground water heat pump, they should be conscious of meeting all the installation requirements to the fullest extent. An improperly sized well or an inadequate pump can lead to an inefficient system, which eventually runs into added expense. Be sure to keep in mind the disposal method most appropriate for the situation. A experienced contractor will help make recommendations.

I recommend the installation of a ground water heat pump. The energy and economic potentials are too large to ignore. Since water is a totally renewable resource, ground water as a heat source will be a part of future energy use and research.

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